R-parity violation searches at LEP

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The present results on R-parity violation searches performed by the four LEP experiments are presented. This concerns mainly the pair and single production of SUSY particles in the hypothesis of R-parity violation ($\not{R}_p$) via explicit trilinear couplings (LL$\bar{\text{E}}$, LQ$\bar{\text{D}}$ and $\bar{\text{U}}\bar{\text{D}}\bar{\text{D}}$) . The chargino pair production search in the spontaneaous R-parity violation by an effective bilinear term ϵ_{i} $\text{H}_{\text{u}}\text{L}_{\text{i}}$ scenario is also presented.

1 Introduction

The most general way to write a superpotential including the symmetries and particle content of the Minimal Supersymmetric extension of the Standard Model (MSSM) [1] is:

$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k \qquad (1)$$

where W_{MSSM} represents interactions between particles consistent with $B-L$ conservation (B = baryon number, L = lepton number) and the other terms describes interactions violating B or L conservation [2]. These latter terms of the superpotential break **explicitly** R-parity ($R_p = (-1)^{3B+2S+L}$). In equation (1), i, j and k are the generation indices; L and $\bar{E}$ denote the left-handed doublet lepton and the right-handed singlet charge-conjugated lepton superfields respectively, whereas Q, $\bar{U}$ and $\bar{D}$ denote the left-handed doublet quark and the right-handed singlet charge-conjugated up- and down-type quark superfields; λ_{ijk}, λ'_{ijk} and λ''_{ijk} are the Yukawa couplings. The first two terms violate L conservation, and the third one B conservation.

The major phenomenological consequences of $\not{R}_p$ is the production of single sneutrino and the decay into standard fermions of the Lightest Supersymmetric Particle, LSP (see Fig. 1). This last property modifies the signatures of the supersymmetric particle decays compared to the expected signatures in case of R-parity conservation.

However, an additional fourth term, ϵ_{i} $\text{H}_{\text{u}}\text{L}_{\text{i}}$, can be added to the superpotentiel of equation (1). This term corresponds to an **effective** bilinear coupling between the left handed lepton superfield and the up-type Higgs field H_u. This effective term comes from the spontaneous $\not{R}_p$ due to a non-zero vacuum expectation values for scalar neutrinos. One possible scenario is to

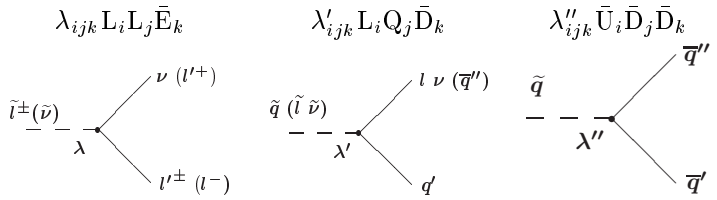

Table 1. Sfermion decay diagrams with trilinear couplings

consider only spontaneous $R\!\!\!/_p$ in the third generation [3]. In this model, called ϵ-model the spontaneous $R\!\!\!/_p$ leads to the existance of a physical, massless and stable Nambu-Golstone boson, called Majoron (J).

2 Decay of SUSY particles

The SUSY particle decays can be either direct or indirect. In the first case, the SUSY particle decays directly or via a virtual SUSY particle exchange to standard particles through an $R\!\!\!/_p$ vertex. In the second case, the SUSY particle decays through an $R\!\!\!/_p$ conserving vertex to a standard particle and an on-shell SUSY particle, which then decays through an $R\!\!\!/_p$ vertex. In the spontaneous $R\!\!\!/_p$ scenario, the chargino is allowed to decay into a tau and a Majoron. The branching ratio of this process depends on the parameter ϵ [3]. Therefore, the experimental signature of the chargino pair production is two acoplanar taus and missing momentum from the undetected Majorons.

3 Searches framework

$R\!\!\!/_p$ LEP searches are performed in a Constrained MSSM. The mass spectrum and the cross-section of the SUSY processes are obtained with the hypotheses of mass universality at GUT scale (μ, $\tan\beta$ and m_0). The gaugino running mass relation at electroweak scale is supposed to be $M_1 \sim 0.5 M_2$. To be consistant with the limit on the proton lifetime, the LEP analyses consider one coupling to be dominant at a time ($LL\bar{E}$, $LQ\bar{D}$, $\bar{U}\bar{D}\bar{D}$ or ϵ_i $H_u L_i$). These analyses consider the $\widetilde{\chi}_1^0$ as the LSP when the indirect decays of $\tilde{f}$ or $\widetilde{\chi}^{\pm}$ are searched whereas the $\tilde{f}$ or the $\widetilde{\chi}^{\pm}$ are the LSP when the direct decay is supposed to be dominant. Finally, it is important to remind that the present analyses are performed with the hypothesis of a short LSP lifetime corresponding to an LSP decay at the primary vertex. Therefore these searches are sensitive to a neutralino mass greater than ~ 10 GeV.

4 LEP2 performance, backgrounds, signal production and analysis strategies

LEP2 corresponds to 5 years of data taking with a centre-of-mass energy up to 209 GeV and a luminosity per experiment $\sim 714\,\mathrm{pb}^{-1}$. For almost all searches the four fermion final states are the main backgrounds. The production of signal has been performed with the SUSYGEN generator [4]. The final states depend on the couplings. Nevertheless, each coupling ($LL\bar{E}$, $LQ\bar{D}$, or $\bar{U}\bar{D}\bar{D}$) is characterize by a dominant topology. The channels assuming the λ_{ijk} coupling have many leptons and missing energy. The channels with λ'_{ijk} couplings have many jets, leptons and missing energy. In the λ''_{ijk} analyses many jets are expected. For all $\not{R}_p$ searches, we expect between 4 (direct decay) and 10 fermions (indirect decay) in the final state and the missing energy had to come from undetectable neutrino or Majoron (Spontaneous $\not{R}_p$ scenario). The number of possible final states is large. Therefore the $\not{R}_p$ LEP searches have to cover many different channels. In general one analysis is optimized for different channels. For example the ALEPH multi-jet analysis corresponds to the 6, 8, and 10 jet topologies of the $\bar{U}\bar{D}\bar{D}$ coupling searches.

The signal selection on the required topology is obtained using sequential cuts (ALEPH, DELPHI, L3, OPAL) and neural network methods (DELPHI). The selection are based on lepton identification and lepton isolation criteria for $LL\bar{E}$ and $LQ\bar{D}$ searches and on jet algorithm and b-tagging variables for the $LQ\bar{D}$ and $\bar{U}\bar{D}\bar{D}$ searches.

5 Results

Unfortunatly, the present preliminary results of the four LEP experiments [5] show no significant deviations from the SM expectations in case of $\not{R}_p$ hypothesis. Therefore these negative results are interpreted in a constrained MSSM framework by setting exclusion limits at 95 % CL on cross-sections, SUSY particle masses (scalar sector) and excluded MSSM regions (gaugini sector). Table 2 summarize the most recent results mainly based on ALEPH and DELPHI preliminary results. The spontaneous $\not{R}_p$ search in DELPHI [7] obtained a limit on the chargino mass at 101 GeV for data taking at a centre-of-mass energy of 202 GeV. The single sneutrino production searches of DELPHI and ALEPH gives limts on the couplings λ around $10^{-2} - 10^{-3}$ depending on the sneutrino masses [6].

Pair production of	LLE		LQD		UDD	
	direct	indirect	direct	indirect	direct	indirect
$\widetilde{\chi}_1^0$	**40**	**40**	-	-	**38**	**38**
$\widetilde{\chi}_1^+$	**103**	**103**	**103**	**103**	**102**	**102**
$\widetilde{e}_R$	**96**	**96**	-	**93**	$\times$	**94**
$\widetilde{\mu}_R$	**87**	**96**	-	**90**	$\times$	**85**
$\widetilde{\tau}_R$	**87**	**95**	-	**76**	$\times$	-
$\widetilde{\nu}_e$	**100**	**98**	-	**91**	$\times$	**88**
$\widetilde{\nu}_\mu$	**90**	**95**	**79**	**78**	$\times$	**65**
$\widetilde{\nu}_\tau$	**90**	**95**	**79**	**78**	$\times$	**65**
$\widetilde{t}_L$	$\times$	**91**	-	**85**	-	**87**
$\widetilde{b}_L$	$\times$	**90**	-	**80**	-	**80**

Table 2. Summary of existing mass limits in GeV/c^2 from $\not{R}_p$ pair production searches of supersymmetric particles at LEP. Each mass limit is obtained under some hypotheses which are not presented in this contribution. The sign $\times$ means not allowed. The sign - means not covered.

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